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THE EFFECTS OF TRACKING STATION POSITION UNCERTAINTIES ON ORBIT DETERMINATION FOR THE GEOS - I SATELLITE

J. G. MARSH
R. W. AGREEN

MAY 1970

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ABSTRACT

A study was made to determine the effect of tracking station location errors on the computed position of the GEOS-I satellite and on the fits of the data to the orbit. This was done by selecting a standard set of precision reduced optical data from a global set of stations and determining a reference orbit and a reference prediction ephemeris of the same length as the definitive orbit (4 days). Then "errors" of 30 and 60 meters were introduced into the positions of various station subgroups and both the definitive orbit and prediction ephemeris were recomputed. The R.M.S. value of satellite position differences in the definitive period corresponding to a 30 meter station "error" in either latitude or longitude ranged from 2.4 to 13.6 meters. During the prediction period satellite position differences for a 30 meter station error ranged from R.M.S. values of 2.3 to 20.2 meters.

Differences in the orbital positions and in the data fits are presented in tabular and graphical form.

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THE EFFECTS OF TRACKING STATION POSITION UNCERTAINTIES ON ORBIT DETERMINATION FOR THE GEOS-I SATELLITE

INTRODUCTION

"Errors" of 30 and 60 meters in the latitude and longitude of station positions are introduced into a standard four-day arc of active GEOS-I precision reduced optical data, and the effect on orbital position and on the data fits to the orbit are determined.

The purpose of this experiment is to observe the effect that station position errors can have on orbit determination and satellite prediction.

DISCUSSION OF THE EXPERIMENT

A four-day GEOS-I arc of NASA Station Tracking and Data Acquisition Network (STADAN), Special Optical Tracking System (SPEOPT), and Smithsonian Astrophysical Observatory (SAO) Baker-Nunn precision reduced optical data was chosen as a standard reference arc, July 13-16, 1966.

The Multi-Arc Multi-Satellite Noname Orbit Determination and Geodetic Parameter Estimation System was used to determine the reference orbit from the 1107 observations of the above arc (Reference 1). The SAO-M1 gravity model modified by the 12th order terms of Gaposchkin and Veis (Reference 2) was used to define the earth's potential, and the stations were referenced to the SAO C-7 ellipsoid (Reference 3).

The number of observations and their RMS of fit to the reference orbit appear in Table 1. Figure 1 shows the locations of all stations which contributed data to the arc. The definitive reference arc was also used to establish a predictive arc over July 17-20, 1966 which was used as a reference prediction ephemeris.

Once the reference orbit had been established, the object of the experiment was to introduce "errors" into the positions of stations and observe what effect these "errors" had on the definitive orbit and on the prediction orbit. Since there are numerous ways in which this type of experiment could be run, it was necessary to select which and how many stations were to be given incorrect station positions, how much of an "error" should be introduced, and in what direction the station should be moved.

Table 1

Data Fits to the Standard GEOS-I Arc July 13-16, 1966

| Network | Station | Number | Location | Number of Observations Used | RMS of Fit (arc secs.) |
|---------|---------|--------------------|----------------------------|-----------------------------------|---------------------------------|
| STADAN | 10OMER | 1024 | Woomera, Australia | 7 * | — |
| | | | | 7** | — |
| | 1JOBUR | 1031 | Johannesburg, S. Africa | 27 | 2.2 |
| | | | | 24 | 3.0 |
| | 1TANAN | 1043 | Tananarive, Madagascar | 14 | 1.1 |
| | | | 14 | 1.7 | |
| SPEOPT | 1BERMD | 7039 | Bermuda | 14 | 2.7 |
| | | | | 14 | 3.1 |
| | 1SUDBR | 7075 | Sudbury, Ontario | 14 | 2.2 |
| | | | | 14 | 1.3 |
| SAO | 1ORGAN | 9001 | Organ Pass, N.M. | 77 | 1.7 |
| | | | | 77 | 1.8 |
| | 1OLFAN | 9002 | Olifantsfontein, S. Africa | 97 | 2.0 |
| | | | | 96 | 2.2 |
| | 1SPAIN | 9004 | San Fernando, Spain | 35 | 2.4 |
| | | | | 35 | 1.7 |
| | 1NATOL | 9006 | Naini Tal, India | 25 | 2.3 |
| | | | | 25 | 1.6 |
| | 1QUIPA | 9007 | Arequipa, Peru | 38 | 2.5 |
| | | | | 41 | 2.2 |
| | 1SHRAZ | 9008 | Shiraz, Iran | 14 | 1.4 |
| | | | | 14 | 2.4 |
| | 1JUPTR | 9010 | Jupiter, Fla. | 112 | 1.7 |
| | | | | 111 | 1.8 |
| | 1VILDO | 9011 | Villa Dolores, Argentina | 20 | 2.4 |
| | | | 17 | 3.4 | |
| 1MAUIO | 9012 | Maui, Hawaii | 28 | 2.7 | |
| | | | 28 | 1.2 | |
| AUSBAK | 9023 | Woomera, Australia | 34 | 2.0 | |
| | | | 34 | 2.0 | |
| | All | — | | 1107 | 2.0 |

*Declination

**Right ascension

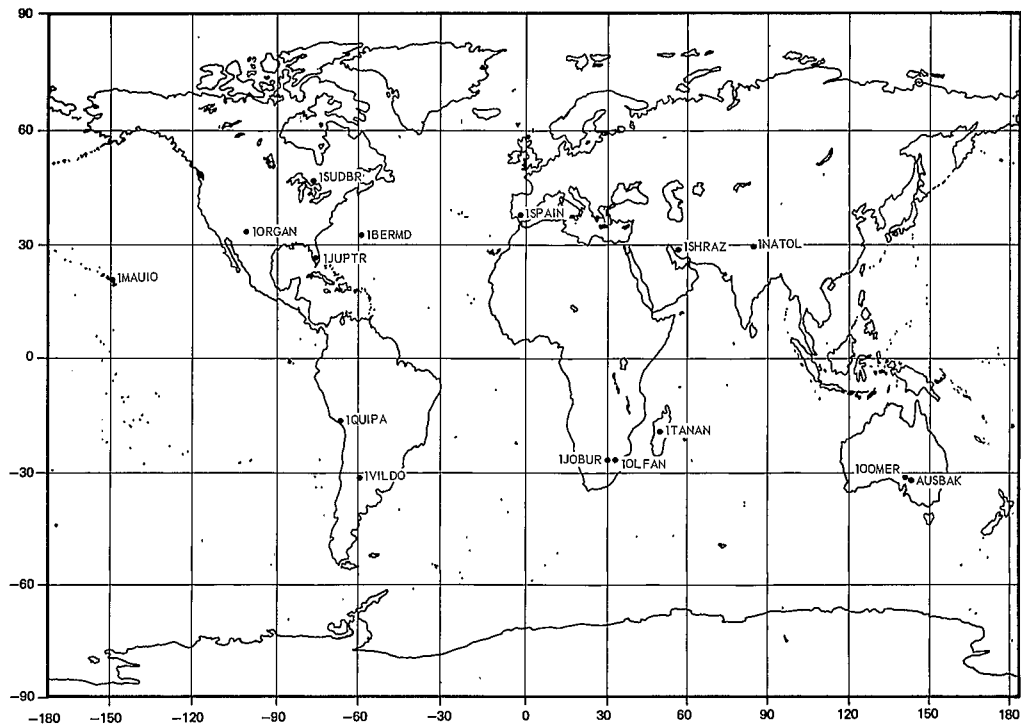


Figure 1. Global Locations of GEOS-1 Optical Stations Contributing Data to All Orbital Determinations

The stations were grouped geographically to make the analysis more meaningful; it was felt that any trends could be more readily recognized if the "errors" were confined to small portions of the globe. Also, this grouping scheme had the advantage of varying the amounts of data to be effected by the introduced "errors". Table 2 lists the groups that were moved and the percentage of the total number of observations they represent.

Table 2
Station Groupings Into Which Errors Were Introduced

| Group Number | Stations In Group | Number of Observations In Base Arc | Percentage of Observations |
|--------------|-------------------|------------------------------------|----------------------------|
| 1 | 1QUIPA | 79 | 10.5 |
| | 1VILDO | 37 | |
| 2 | 1JOBUR | 51 | 24.6 |
| | 1OLFAN | 193 | |
| | 1TANAN | 28 | |
| 3 | 1OOMER | 14 | 7.4 |
| | AUSBAK | 68 | |
| 4 | 1MAUIO | 56 | 5.1 |
| 5 | 1ORGAN | 154 | 13.9 |
| 6 | 1JUPTR | 223 | 20.1 |
| 7 | 1NATOL | 50 | 7.0 |
| | 1SHRAZ | 28 | |
| | All | 981 | 88.6 |

Desiring to keep the initial experiment as basic as possible, it was decided to leave the height of the station unchanged due to the general insignificance of radial orbital errors when compared to cross track and particularly along track errors. Along similar lines of thought, the "errors" were introduced into latitude only and then longitude only since combinations were considered to be secondary and yield more complex analytical questions.

It was thus determined to move the groups of stations as they appear in Table 2 by ± 30 meters in latitude and then longitude, which is a rather pessimistic uncertainty for most of the stations used in this study. To make trends more noticeable, two groups of stations were moved by ± 60 meters in latitude and then longitude. These decisions made for 36 orbit determination computer runs and 36 more predictive arc runs to enable comparisons over both definitive and predictive periods. In all of these runs, the number of observations was held fixed.

In order to move the stations by a certain number of meters in latitude and longitude, the following formulas for conversion of meters into degrees of latitude and longitude were used (Reference 3):

$$1 \text{ meter} \approx [111133.35 - 559.84 \cos 2\phi]^{-1} \text{ degrees latitude}$$

$$1 \text{ meter} \approx [111413.28 \cos \phi]^{-1} \text{ degrees longitude}$$

where ϕ = latitude of the station.

RESULTS

The major results of the experiment appear in Table 3. All orbits determined with incorrect station positions were compared with both the definitive and predictive reference orbits. The RMS of position differences between the standard and test case orbits over the eight day period are tabulated. It is seen that effects due to the movement of a station or group of stations by 30 meters is dependent, to an extent, upon the percentage of data represented by the stations and the distribution of the stations.

The range of RMS differences for 30 meter movements on the definitive orbit is 2.4 to 13.6 meters and on the predictive orbit is 2.3 to 20.2 meters. For 60 meter movements, the respective ranges are 9.5 to 26.7 and 10.3 to 30.8 meters.

The predict period differences are slightly larger than the definitive period differences, in general. In some cases, the reverse occurs. In other cases, the

Table 3

Comparisons of Orbits With Errors Introduced Into Station Positions
Against the Reference Definitive and Predictive Orbits

| Station Group | Adjustment of Coordinates* | RMS of Satellite Position Differences (meters) | | | | | | | |
|------------------------------------|----------------------------|--|-------------|-------------|-------|---------------------------|-------------|-------------|-------|
| | | Definitive Arc July 13-16 | | | | Predictive Arc July 17-20 | | | |
| | | Radial | Cross Track | Along Track | Total | Radial | Cross Track | Along Track | Total |
| 1MAUIO (5.1% of data) | +30 ϕ | 1.1 | 1.2 | 3.5 | 3.8 | 1.2 | 1.1 | 4.0 | 4.3 |
| | -30 ϕ | 0.6 | 0.9 | 3.7 | 3.9 | 0.9 | 0.9 | 12.5 | 12.6 |
| | +30 λ | 1.0 | 0.9 | 4.2 | 4.4 | 0.9 | 0.8 | 5.8 | 5.9 |
| | -30 λ | 0.5 | 1.2 | 2.8 | 3.0 | 0.8 | 1.0 | 11.0 | 11.0 |
| 1ORGAN (13.9% of data) | +30 ϕ | 1.1 | 2.6 | 3.0 | 4.1 | 0.9 | 2.4 | 3.5 | 4.3 |
| | -30 ϕ | 1.3 | 2.5 | 6.9 | 7.4 | 1.4 | 2.3 | 4.3 | 5.1 |
| | +30 λ | 1.6 | 3.2 | 4.9 | 6.1 | 1.6 | 3.0 | 5.4 | 6.4 |
| | -30 λ | 1.9 | 3.3 | 10.2 | 10.9 | 1.8 | 3.1 | 15.3 | 15.7 |
| 1JUPTR (20.1% of data) | +30 ϕ | 1.8 | 3.6 | 3.8 | 5.5 | 1.8 | 3.3 | 5.0 | 6.2 |
| | -30 ϕ | 1.5 | 3.4 | 4.9 | 6.1 | 1.5 | 3.2 | 3.6 | 5.0 |
| | +30 λ | 1.4 | 4.5 | 2.9 | 5.5 | 1.4 | 4.1 | 3.6 | 5.6 |
| | -30 λ | 1.3 | 4.7 | 4.0 | 6.3 | 1.3 | 4.2 | 6.3 | 7.7 |
| 1NATOL 1SHRAZ (7.0% of data) | +30 ϕ | 0.7 | 1.9 | 1.6 | 2.5 | 0.6 | 1.7 | 1.5 | 2.3 |
| | -30 ϕ | 0.8 | 1.7 | 3.6 | 4.1 | 1.0 | 1.6 | 3.8 | 4.3 |
| | +30 λ | 0.5 | 1.9 | 1.3 | 2.4 | 0.5 | 1.8 | 3.8 | 4.2 |
| | -30 λ | 0.9 | 2.1 | 4.5 | 5.0 | 1.0 | 1.9 | 3.9 | 4.5 |

*30 ϕ = latitude adjustment of 30 meters

30 λ = longitude adjustment of 30 meters

Table 3 (Continued)

| Station Group | Adjustment of Coordinates | RMS of Satellite Position Differences (meters) | | | | | | | |
|---|---------------------------|--|-------------|-------------|-------|---------------------------|-------------|-------------|-------|
| | | Definitive Arc July 13-16 | | | | Predictive Arc July 17-20 | | | |
| | | Radial | Cross Track | Along Track | Total | Radial | Cross Track | Along Track | Total |
| 1QUIPA 1VILDO (10.5% of data) | +30 ϕ | 1.5 | 2.5 | 4.8 | 5.7 | 1.5 | 2.8 | 5.3 | 6.2 |
| | -30 ϕ | 1.8 | 2.8 | 3.6 | 4.9 | 1.9 | 3.1 | 6.0 | 7.0 |
| | +30 λ | 1.7 | 4.1 | 5.0 | 6.7 | 1.5 | 4.6 | 9.1 | 10.3 |
| | -30 λ | 1.3 | 4.4 | 3.4 | 5.7 | 1.5 | 4.9 | 5.0 | 7.2 |
| 1JOBUR 1OLFAN 1TANAN (24.6% of data) | +30 ϕ | 3.3 | 6.6 | 9.5 | 12.1 | 3.7 | 7.4 | 18.5 | 20.2 |
| | -30 ϕ | 3.6 | 7.0 | 7.1 | 10.6 | 3.6 | 7.8 | 8.7 | 12.2 |
| | +30 λ | 2.5 | 9.8 | 6.7 | 12.2 | 2.6 | 11.1 | 5.8 | 12.8 |
| | -30 λ | 2.5 | 10.1 | 8.6 | 13.6 | 2.7 | 11.4 | 8.3 | 14.4 |
| | +60 ϕ | 6.7 | 13.4 | 16.0 | 21.9 | 6.9 | 15.0 | 25.1 | 30.1 |
| | -60 ϕ | 7.0 | 13.8 | 14.6 | 21.3 | 7.0 | 15.4 | 18.2 | 24.8 |
| | +60 λ | 5.0 | 19.8 | 14.4 | 25.0 | 5.6 | 22.3 | 19.6 | 30.2 |
| | -60 λ | 5.0 | 20.1 | 16.8 | 26.7 | 5.5 | 22.7 | 20.1 | 30.8 |
| 1OOMER AUSBAK (7.4% of data) | +30 ϕ | 1.5 | 3.2 | 6.2 | 7.2 | 1.5 | 3.6 | 3.8 | 5.4 |
| | -30 ϕ | 1.3 | 3.5 | 3.3 | 5.0 | 1.2 | 3.9 | 5.3 | 6.7 |
| | +30 λ | 1.3 | 4.0 | 3.5 | 5.5 | 1.2 | 4.5 | 7.3 | 8.6 |
| | -30 λ | 0.7 | 4.3 | 1.8 | 4.7 | 0.6 | 4.8 | 6.4 | 8.0 |
| | +60 ϕ | 2.9 | 6.6 | 10.7 | 12.9 | 2.9 | 7.3 | 6.7 | 10.3 |
| | -60 ϕ | 2.7 | 6.9 | 8.5 | 11.2 | 2.6 | 7.6 | 6.7 | 10.5 |
| | +60 λ | 2.3 | 8.1 | 5.7 | 10.2 | 2.4 | 9.1 | 7.4 | 12.0 |
| | -60 λ | 1.8 | 8.4 | 4.0 | 9.5 | 1.6 | 9.4 | 9.1 | 13.2 |

predictive period indicated a rapid separation of the orbits along track and the total RMS of position difference increased substantially over the definitive period.

The importance of Table 3, though, lies in the fact that the results are consistent enough to give the reader a good indication of how accurate the station position must be to determine an orbit of desired quality. This would be relevant to a decision of whether or not to use a station's data in some orbit determination work based on only an idea of how well its position is determined and what amounts of data it can contribute.

The results shown in Table 4 indicate that it is very difficult to see station position errors in the total RMS of fit of data to an orbit. However, examination of the RMS of fit by station yields some indication that station position errors exist. This can be seen in Appendix B which shows how the data from each particular station in the orbit was affected by the various movements of other stations and possibly itself.

Table 4

Total RMS of Fit of the Data to the Various GEOS-I Orbital Solutions
(1107 Observations)

| Stations Moved In the Arc | Meters Moved and Direction* | RMS of Fit (arc secs) | | |
|------------------------------|--------------------------------|-----------------------|-------------|-------|
| | | Right Ascension | Declination | Total |
| None (base arc) | — | 2.0 | 2.0 | 2.0 |
| 1QUIPA | +30 ϕ , North | 2.0 | 2.3 | 2.1 |
| 1VILDO | -30 ϕ , South | 2.1 | 2.2 | 2.1 |
| (10.5% of data) | +30 λ , East | 2.5 | 2.1 | 2.3 |
| | -30 λ , West | 1.8 | 1.9 | 1.9 |
| 1JOBUR | +30 ϕ N | 2.1 | 2.5 | 2.3 |
| 1OLFAN | -30 ϕ S | 2.0 | 2.1 | 2.1 |
| 1TANAN | +30 λ E | 1.9 | 2.0 | 2.0 |
| (24.6% of data) | -30 λ W | 2.6 | 2.1 | 2.3 |
| | +60 ϕ N | 2.2 | 3.2 | 2.8 |
| | -60 ϕ S | 2.0 | 2.7 | 2.4 |
| | +60 λ E | 2.2 | 2.1 | 2.2 |
| | -60 λ W | 3.4 | 2.3 | 2.9 |
| | | | | |
| 1OOMER | +30 ϕ N | 2.0 | 2.0 | 2.0 |
| AUSBAK | -30 ϕ S | 2.0 | 2.3 | 2.2 |
| (7.4% of data) | +30 λ E | 2.1 | 2.0 | 2.1 |
| | -30 λ W | 2.2 | 2.1 | 2.1 |
| | +60 ϕ N | 2.1 | 2.3 | 2.2 |
| | -60 ϕ S | 2.1 | 2.8 | 2.5 |
| | +60 λ E | 2.5 | 2.0 | 2.3 |
| | -60 λ W | 2.6 | 2.2 | 2.4 |

* ϕ = latitude, λ = longitude

Table 4 (Continued)

| Stations Moved In the Arc | Meters Moved and Direction* | RMS of Fit (arc secs) | | |
|------------------------------------|--------------------------------|-----------------------|-------------|-------|
| | | Right Ascension | Declination | Total |
| 1MAUIO (5.1% of data) | +30 ϕ N | 2.0 | 2.2 | 2.1 |
| | -30 ϕ S | 2.0 | 2.0 | 2.0 |
| | +30 λ E | 2.0 | 2.0 | 2.1 |
| | -30 λ W | 2.0 | 2.0 | 2.0 |
| 1ORGAN (13.9% of data) | +30 ϕ N | 2.0 | 2.0 | 2.0 |
| | -30 ϕ S | 2.0 | 2.2 | 2.1 |
| | +30 λ E | 2.1 | 2.0 | 2.1 |
| | -30 λ W | 2.0 | 2.1 | 2.1 |
| 1JUPTR (20.1% of data) | +30 ϕ N | 2.1 | 2.2 | 2.2 |
| | -30 ϕ S | 1.9 | 2.1 | 2.1 |
| | +30 λ E | 2.1 | 2.0 | 2.1 |
| | -30 λ W | 2.1 | 2.1 | 2.1 |
| 1NATOL 1SHRAZ (7.0% of data) | +30 ϕ N | 2.0 | 2.1 | 2.0 |
| | -30 ϕ S | 2.0 | 2.1 | 2.1 |
| | +30 λ E | 2.0 | 2.0 | 2.0 |
| | -30 λ W | 2.1 | 2.1 | 2.1 |

* ϕ = latitude, λ = longitude

The value of the data in Appendix B, again, is to provide a "feeling" for how well the data and the orbit adjusts to errors in station positions. In order to approximate the jumps in RMS of fit by meters, it is easily shown that at GEOS-I heights of about 1,500 km, 2 arc seconds is equivalent to approximately 15 meters in satellite position.

There exist a number of interesting trends in the data in Appendix B. First of all, the orbital computation tends to reduce the effect of errors in station position. As an example, although 1JUPTR represented 1/5 of all the data in the orbit, movements of the station's position by 30 meters in the four different directions effected a maximum change in RMS of fit of the 1JUPTR data to the orbits of only 0.6 arc seconds (refer to Table 3), roughly 5 meters. This means that the orbits based on the "wrong" station positions fit the data quite a bit better than one might expect.

Secondly, there seems to be a hemispheric effect — errors introduced into northern hemisphere stations have a greater effect on the data fits of other northern stations than on southern stations and vice versa. This is very obvious for the southern hemisphere stations and not quite as obvious for northern hemisphere stations, possibly because the movement of the south African stations represents a direct effect on 25% of all orbital data.

The third effect is that, in general, errors in latitude show up largely in the declination measurements and errors in longitude effect the right ascension measurements. This is true because topocentric right ascension is measured in a plane that lies parallel to the equator and topocentric declination is measured in a plane formed by the North celestial pole axis and the satellite (see Figure 2).

There are exceptions to the latter two trends, but in general, they are phenomena explainable by the geometry involved.

One aspect of geometry which may have caused the effects of the "errors" to be enhanced is that all optical stations which tracked GEOS-I during this

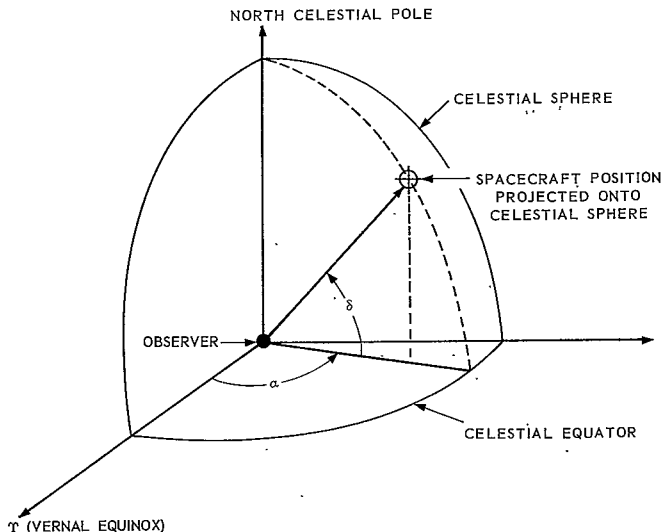


Figure 2. Topocentric Right Ascension (α) and Declination (δ) Angles

period always tracked as the satellite passed from southwest to northeast over the station. This is due to the slow movement of the right ascension of the ascending node, which was in the Earth's shadow, and the requirement of tracking the optical flashes at night. The effect this had on the "errors" was to prevent cancellation of effects. Such cancellation would have occurred if the satellite observational data used in this study had been recorded by an electronic system which provided both daytime and nighttime tracking and thus ground track geometry on all sides of the station.

CONCLUSIONS

It has been shown that errors in one station position on the order of 30 meters cause a 4-day orbit based upon data from a number of other stations also to be perturbed by anywhere from 3.0 to 10.9 meters in root mean square position, depending on the amount of data contributed to the orbit by the particular station and on the direction of the error introduced. When a group of two or three geographically close stations was moved by 30 meters, satellite position differences ranged from 2.4 to 13.6 meters RMS. The orbit differences when two groups of stations were moved by 60 meters ranged from 9.5 to 26.7 meters RMS. The corresponding differences for a predictive four day arc were, in general, slightly larger.

The important result of this study is that although errors in station position do have an effect on moving the plane of the orbit and the position of the satellite in the orbit, this effect is not obvious in the overall fit of the data to the orbit. In order to see any possible error in station position, the RMS of fit of the data from a particular station to the orbit must be examined and it will not necessarily be conclusive in itself for errors on the order of 30 meters. This is obvious because errors in any one station can and usually do increase the RMS fit of data of other stations to the orbit. Thus it seems fair to say that errors on the order of 30 meters in station position can not be detected by examining the data fits of any one orbital solution.

ACKNOWLEDGMENT

The authors wish to thank Mr. Thomas David Meadows for performing the Noname System Computer runs used for this study.

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APPENDIX A

EPHEMERIS PLOTS SHOWING MOVEMENT OF THE ORBIT DUE TO VARIOUS ERRORS IN STATION POSITION

Figures 1 through 6 present a number of representative plots of definitive and predictive ephemeris position differences. In each case, the ephemeris generated with false station positions is compared against the reference ephemeris; three 12 hour periods at the beginning, middle, and end of the 4 day arc are covered in each case. The orbit based on false station positions was compared every ten minutes with the reference definitive and predictive orbit. To present all 72 possible comparisons was thought to be too voluminous, so only a number of representative plots appear.

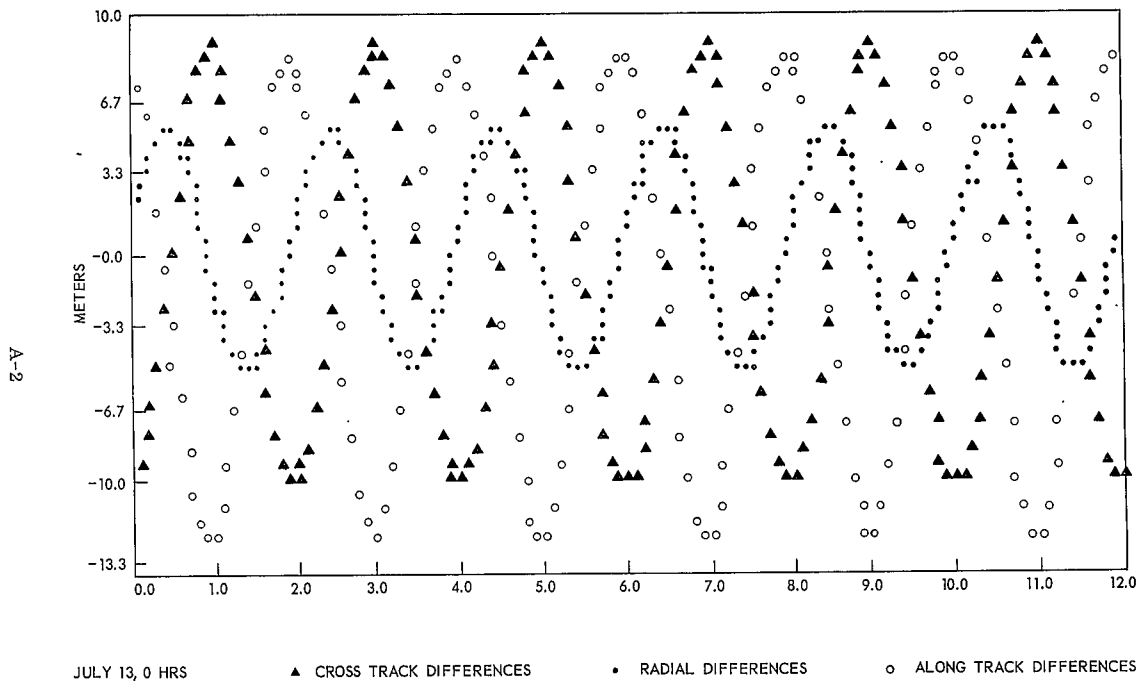
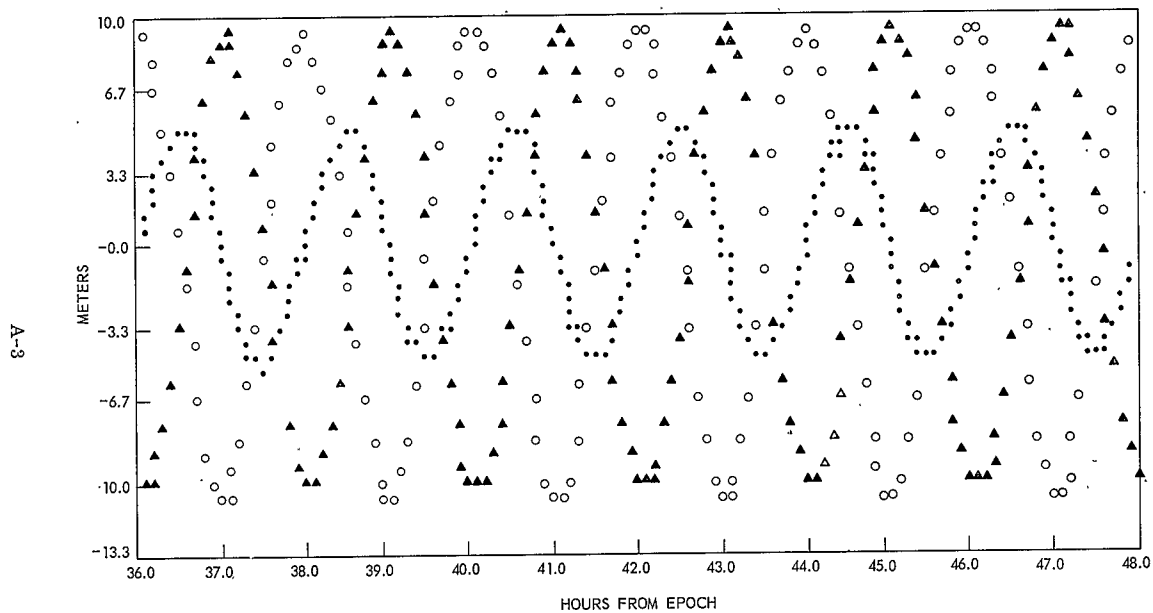
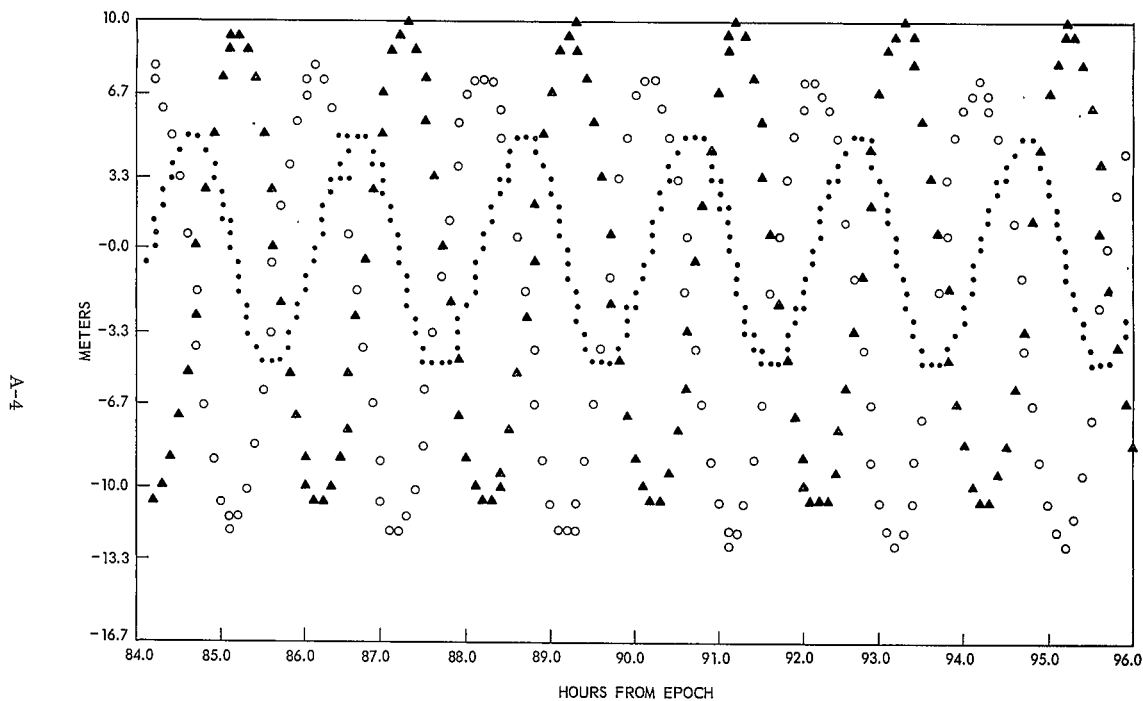


Figure A-1. Reference Definitive Orbit (July 13-16, 1966) versus the Orbit Determined After the Movement of
 1JOBUR, 1OLFAN, and 1TANAN by -30 Meters in Latitude (Page 1 of 3)



JULY 14, 12 HRS

Figure A-1. Reference Definitive Orbit (July 13-16, 1966) versus the Orbit Determined After the Movement of 1JOBUR, 1OLFAN, and 1TANAN by -30 Meters in Latitude (Page 2 of 3)



JULY 16, 12 HRS

Figure A-1. Reference Definitive Orbit (July 13-16, 1966) versus the Orbit Determined After the Movement of IJOBUR, IOLFAN, and ITANAN by -30 Meters in Latitude (Page 3 of 3)

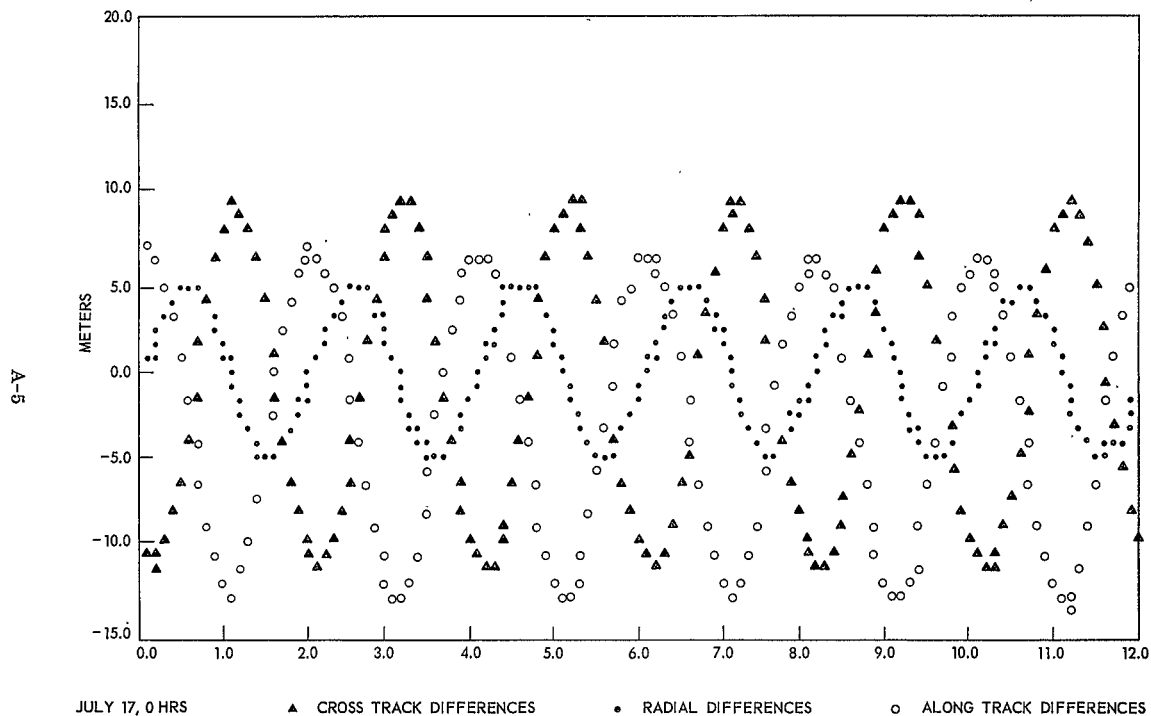
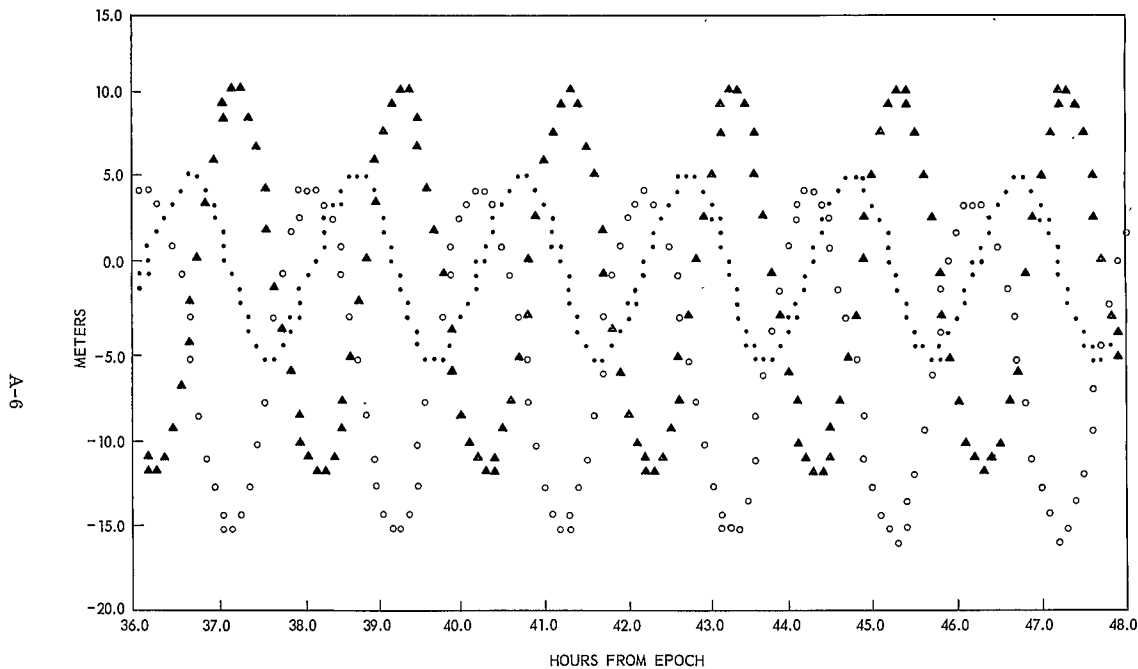
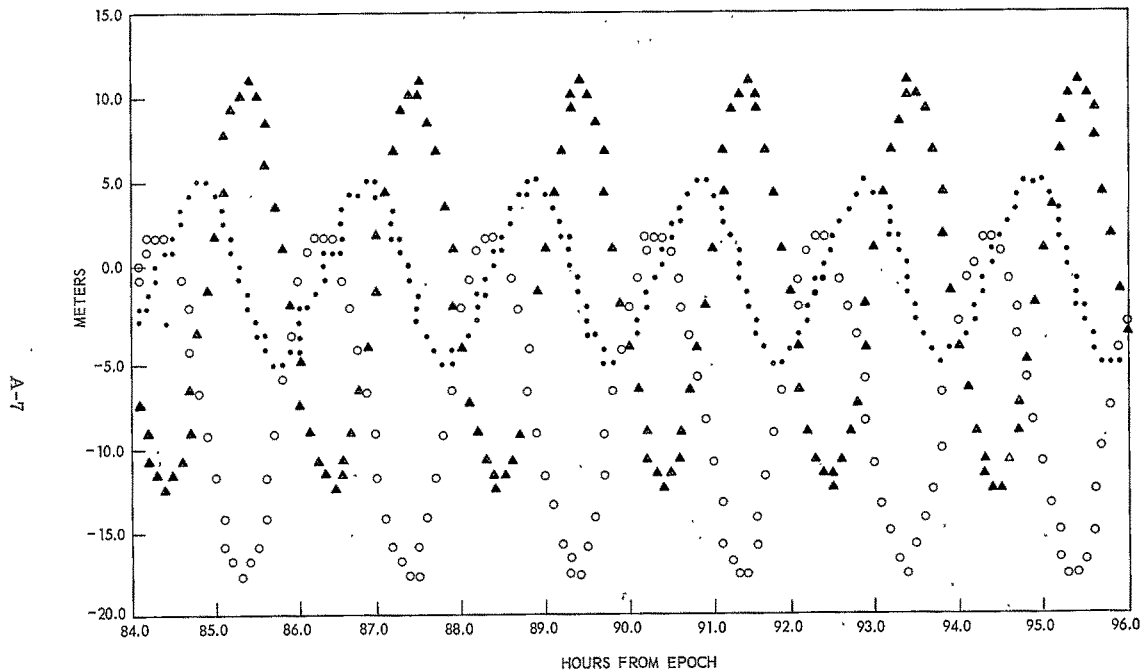


Figure A-2. Reference Predictive Orbit (July 17-20, 1966) versus the Orbit Determined After the Movement of 1JOBUR, 1OLFAN, and 1TANAN by -30 Meters in Latitude (Page 1 of 3)



JULY 18, 12 HRS

Figure A-2. Reference Predictive Orbit (July 17-20, 1966) versus the Orbit Determined After the Movement of 1JOBUR, 1OLFAN, and 1TANAN by -30 Meters in Latitude (Page 2 of 3)



JULY 20, 12 HRS

Figure A-2. Reference Predictive Orbit (July 17-20, 1966) versus the Orbit Determined After the Movement of 1JOBUR, 1OLFAN, and 1TANAN by -30 Meters in Latitude (Page 3 of 3)

A-8

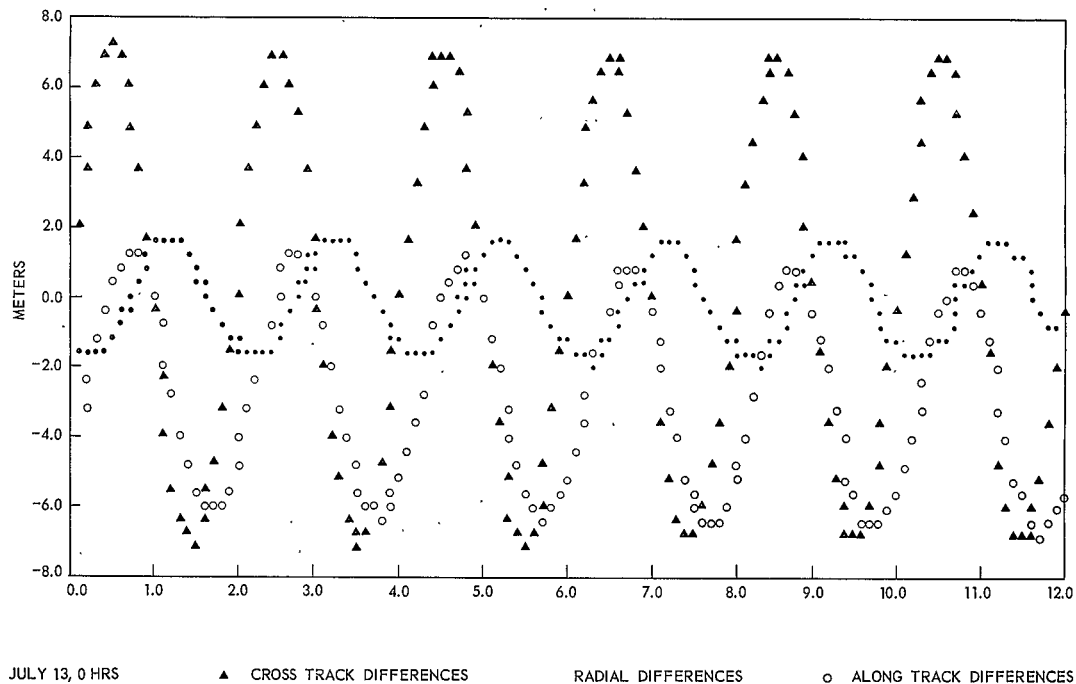
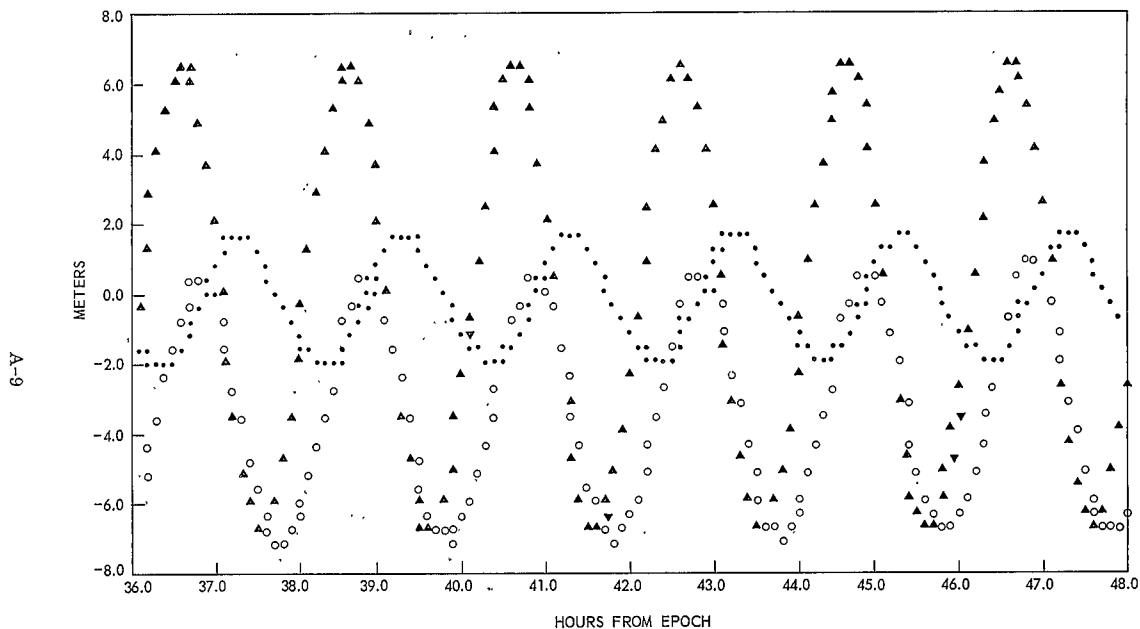
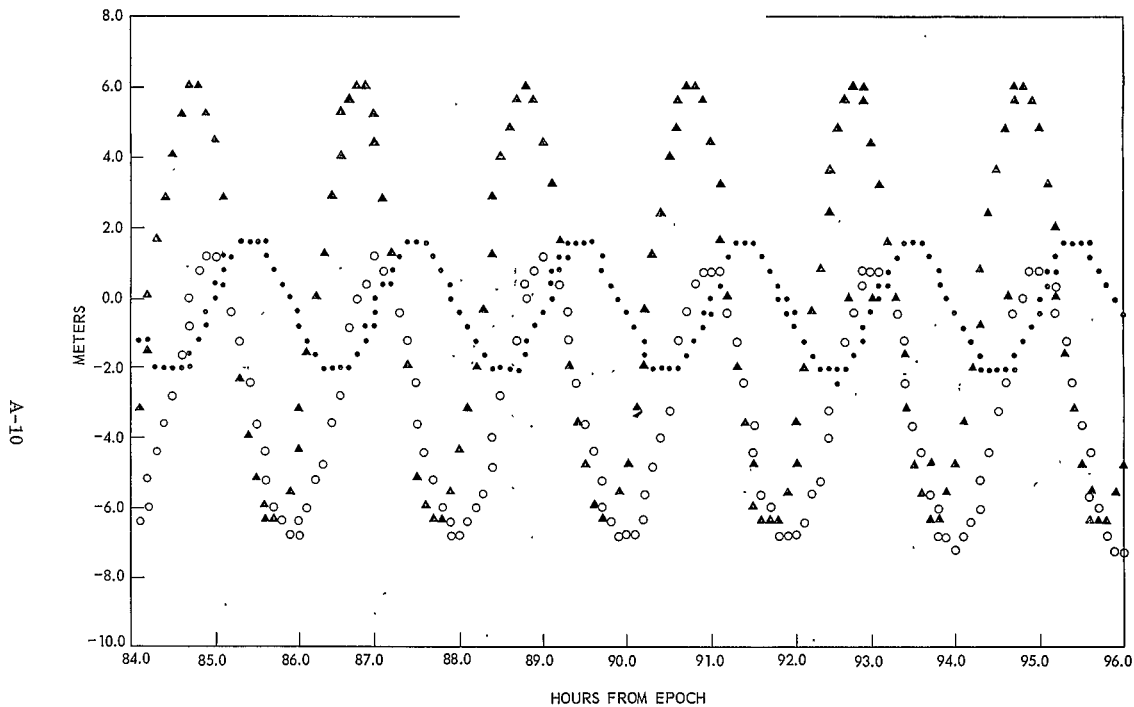


Figure A-3. Reference Definitive Orbit (July 13-16, 1966) versus the Orbit Determined After the Movement of 1JUPTR by -30 Meters in Longitude (Page 1 of 3)



JULY 14, 12 HRS

Figure A-3. Reference Definitive Orbit (July 13-16, 1966) versus the Orbit Determined After the Movement of JUPTR by -30 Meters in Longitude (Page 2 of 3)



JULY 16, 12 HRS

Figure A-3. Reference Definitive Orbit (July 13-16, 1966) versus the Orbit Determined After the Movement of 1JUPTR by -30 Meters in Longitude (Page 3 of 3)

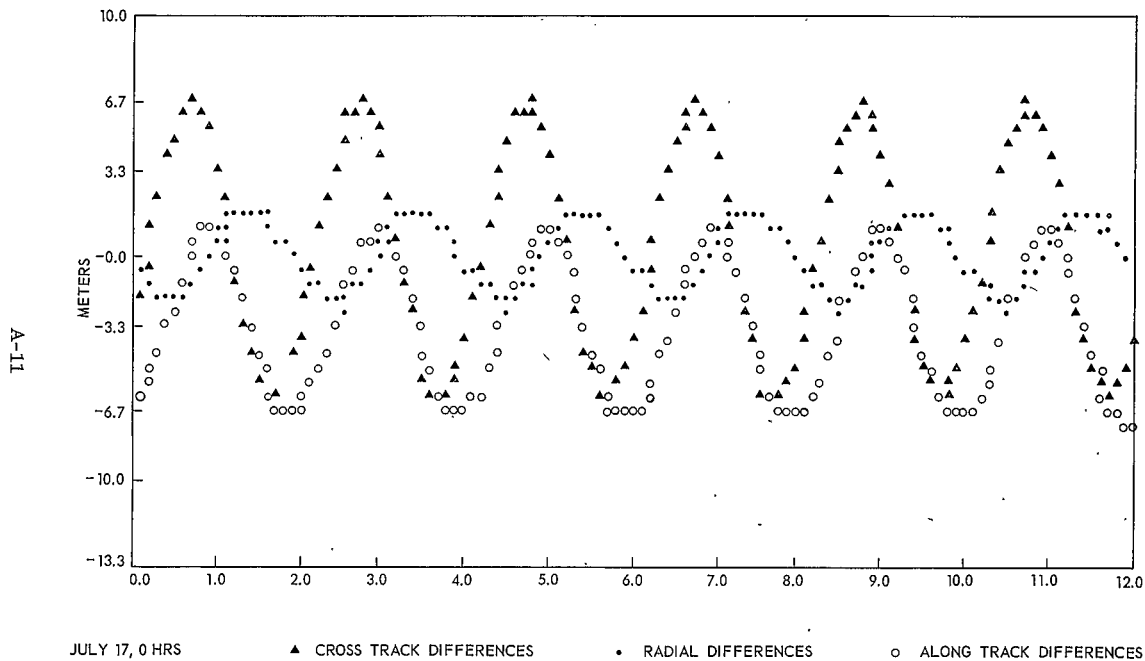
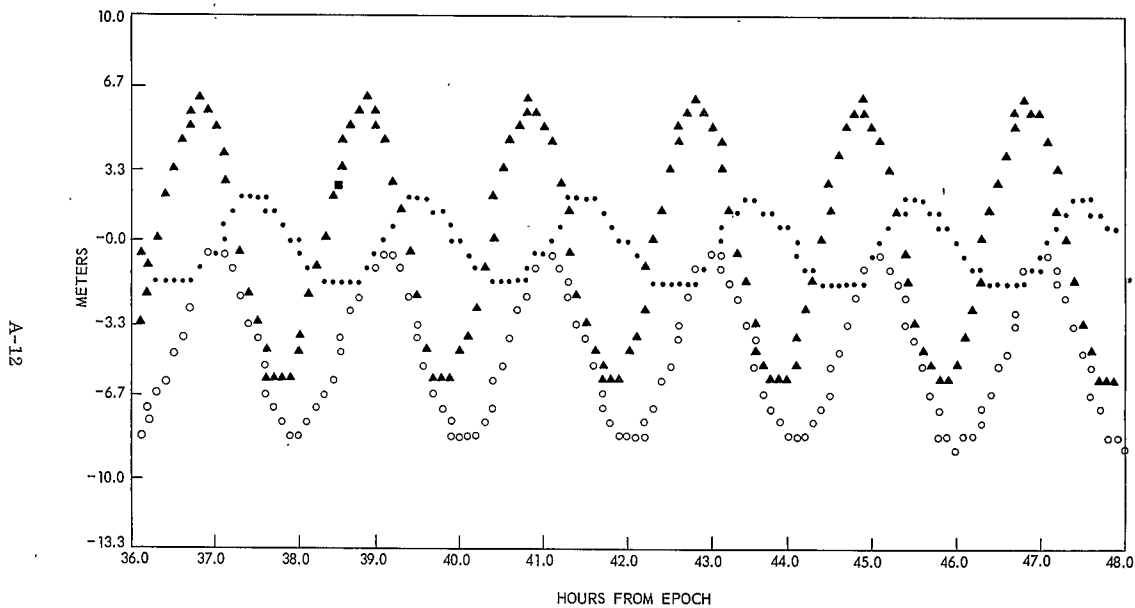
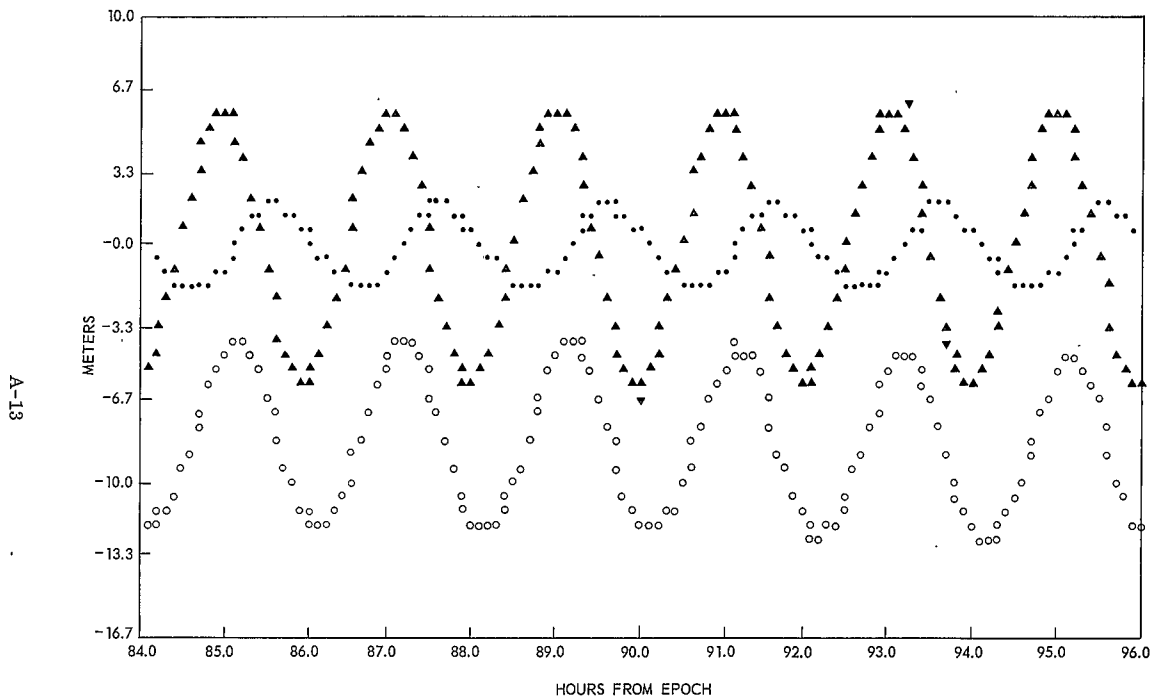


Figure A-4. Reference Predictive Orbit (July 17-20, 1966) versus the Orbit Determined After the Movement of 1JUPTR by -30 Meters in Longitude (Page 1 of 3)



JULY 18, 12 HRS

Figure A-4. Reference Predictive Orbit (July 17-20, 1966) versus the Orbit Determined After the Movement of 1JUPTR by -30 Meters in Longitude (Page 2 of 3)



JULY 20, 12 HRS

Figure A-4. Reference Predictive Orbit (July 17-20, 1966) versus the Orbit Determined After the Movement of 1JUPTR by -30 Meters in Longitude (Page 3 of 3)

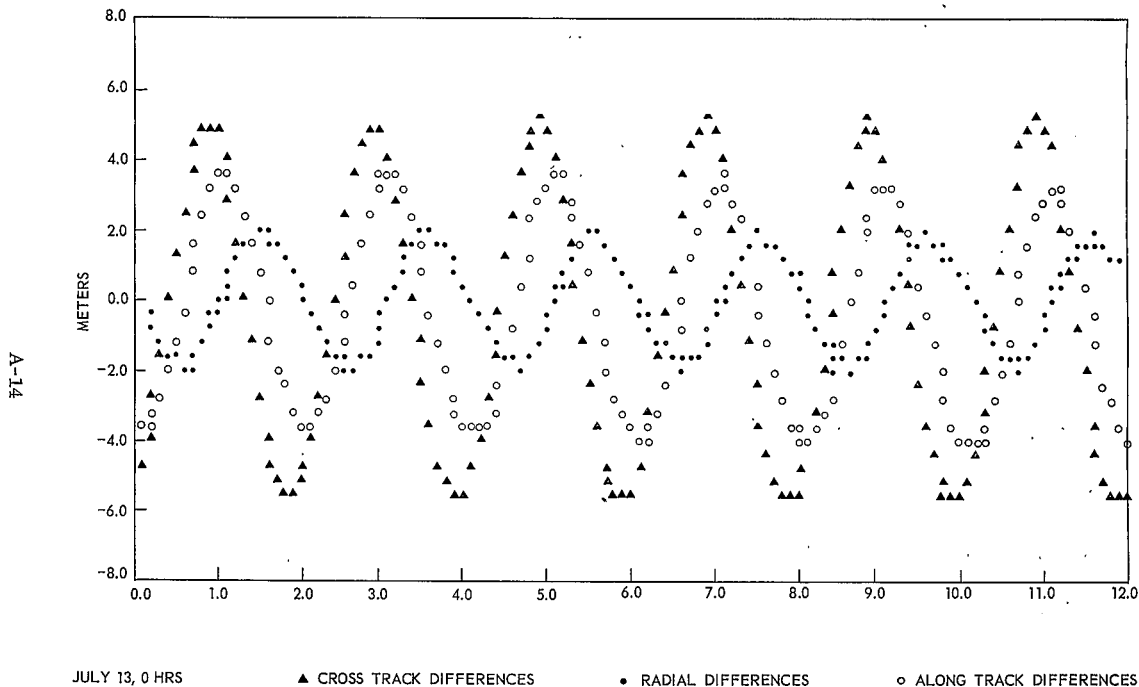
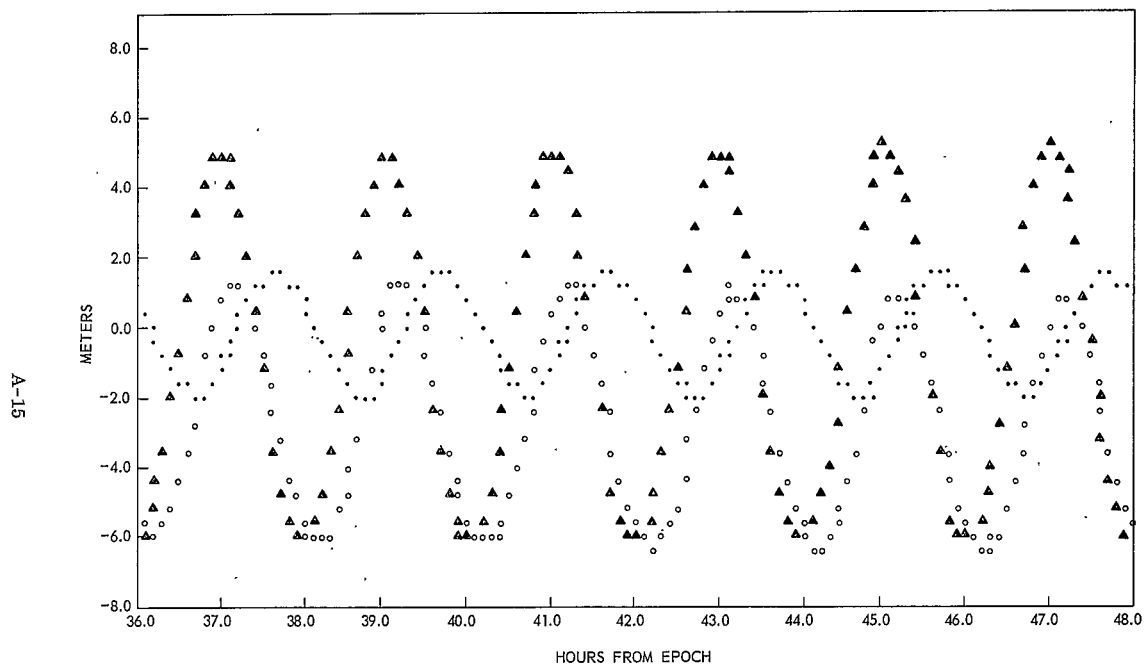


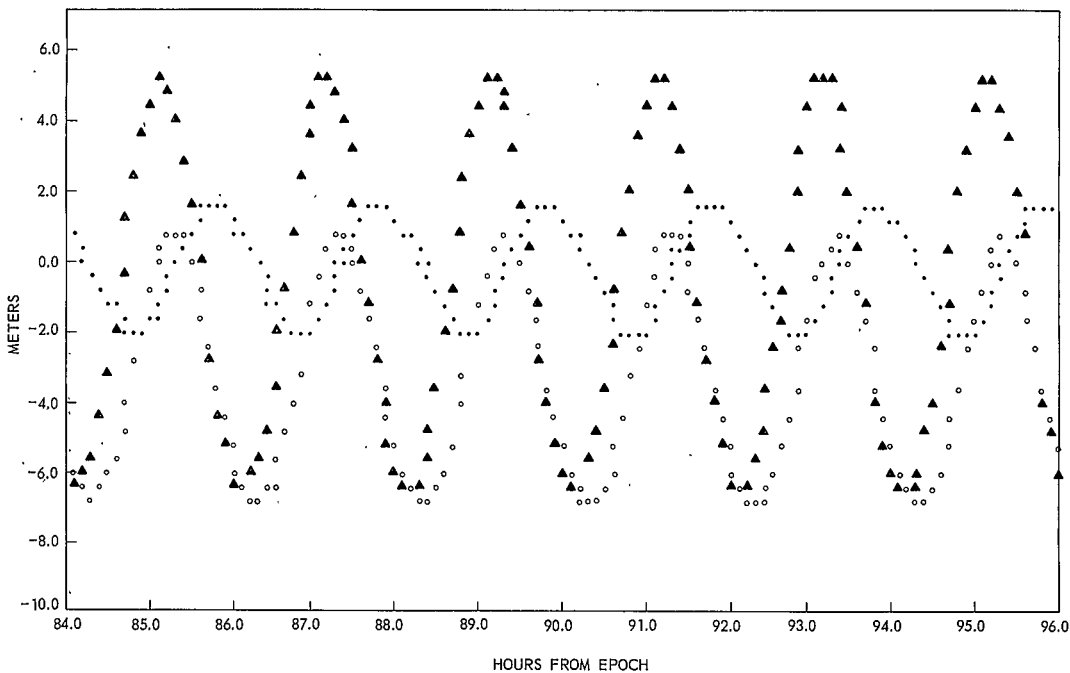
Figure A-5. Reference Definitive Orbit (July 13-16, 1966) versus the Orbit Determined After the Movement of TOOMER and AUSBAK by +30 Meters in Longitude (Page 1 of 3)



JULY 14, 12 HRS

Figure A-5. Reference Definitive Orbit (July 13-16, 1966) versus the Orbit Determined After the Movement of IOOMER and AUSBAK by +30 Meters in Longitude (Page 2 of 3)

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JULY 16, 12 HRS

Figure A-5. Reference Definitive Orbit (July 13-16, 1966) versus the Orbit Determined After the Movement of IOOMER and AUSBAK by +30 Meters in Longitude (Page 3 of 3)

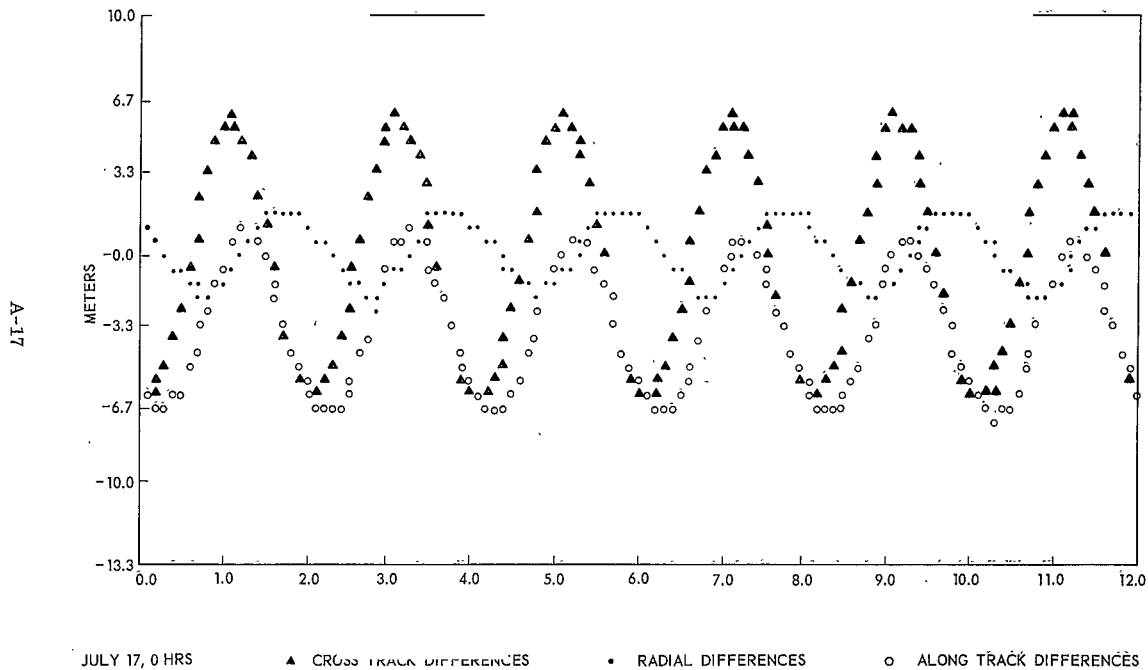
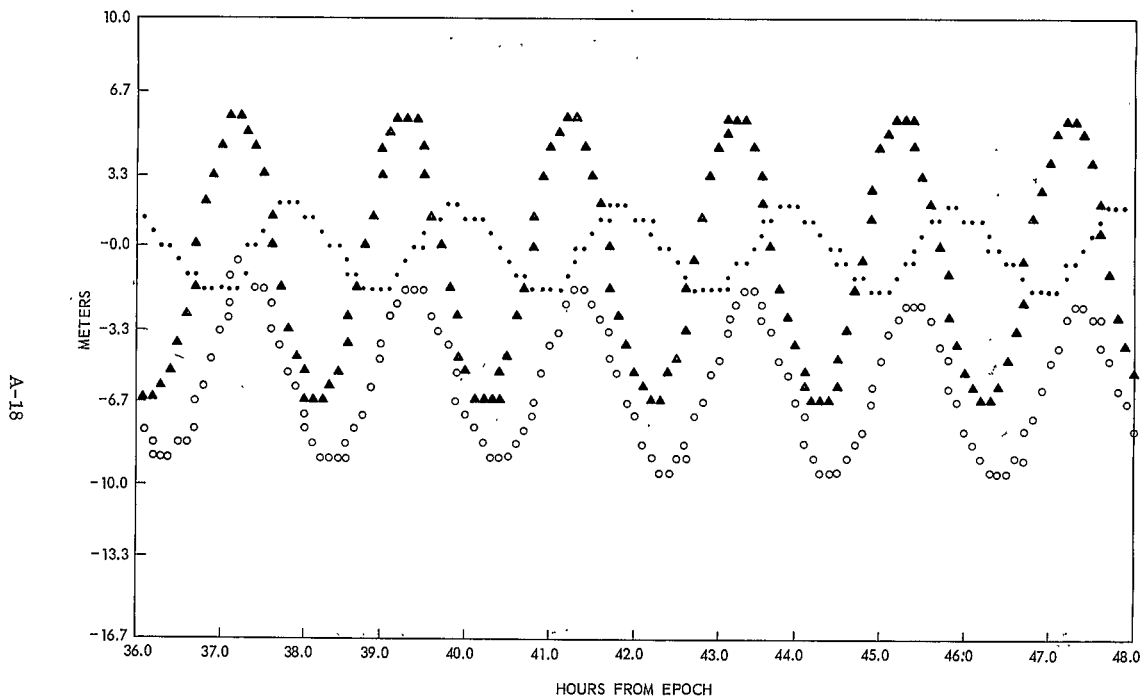
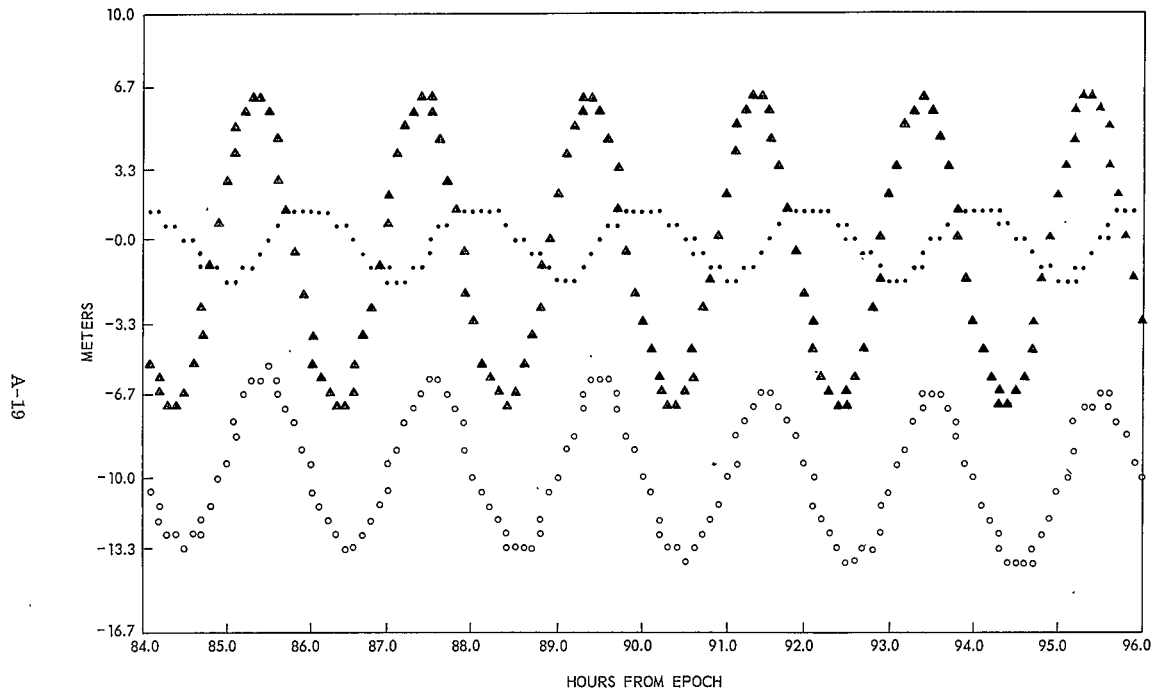


Figure 6. Reference Predictive Orbit (July 17-20, 1966) versus the Orbit Determined After the Movement of IOOMER and AUSBAK by +30 Meters in Longitude (Page 1 of 3)



JULY 18, 12 HRS

Figure 6. Reference Predictive Orbit (July 17-20, 1966) versus the Orbit Determined After the Movement of JOOMER and AUSBK by +30 Meters in Longitude (Page 2 of 3)



JULY 20, 12 HRS

Figure 6. Reference Predictive Orbit (July 17-20, 1966) versus the Orbit Determined After the Movement of 100MER and AUSBK by +30 Meters in Longitude (Page 3 of 3)

APPENDIX B

TABLES OF DATA FITS TO ALL ORBITS FOR EACH STATION

The tables of this appendix illustrate the effects that all of the position errors introduced into station groupings or individual stations had on the data fits of each station to the orbit. By looking at each table, one can observe how the data fits of one station to the orbit were effected by the 36 different orbits created from station position movements.

A table does not appear for the STADAN station LOOMER due to the relatively few observations from that station.

Effect of Errors Introduced Into the Station Positions of Various Stations or Station Groupings
on the RMS of Fit of Maui Data^o

| Station or Station Groups Into Which Errors Were Introduced to Determine New Orbits | Measurement Type | Change in RMS of fit (seconds of arc) due to station position shifts of | | | | | | | |
|---|------------------|---|--------------|--------------------------|-----------------|--------------|--------------|-----------------|-----------------|
| | | +30 m ϕ^\dagger | -30 m ϕ | +30 m λ^\ddagger | -30 m λ | +60 m ϕ | -60 m ϕ | +60 m λ | -60 m λ |
| Maui | δ^* | +1.8 | -.8 | +5 | 0 | | | | |
| | α^{**} | +2 | +3 | +1.1 | +8 | | | | |
| Organ Pass | δ | -.2 | +2 | 0 | +3 | | | | |
| | α | +1 | 0 | 0 | +1 | | | | |
| Jupiter | δ | -.3 | +4 | -.1 | 0 | | | | |
| | α | +1 | 0 | +1 | +1 | | | | |
| Naini Tal, | δ | -.1 | +1 | 0 | 0 | | | | |
| Shiraz | α | 0 | 0 | 0 | +1 | | | | |
| Arequipa, | δ | +2 | -.2 | +1 | +2 | | | | |
| Villa Dolores | α | 0 | 0 | 0 | +1 | | | | |
| Johannesburg, | δ | +8 | -.4 | 0 | 0 | +1.3 | -.7 | -.1 | +1 |
| Olifantsfontein, | α | +1 | 0 | +2 | +2 | +1 | +1 | +5 | +5 |
| Tananarive | | | | | | | | | |
| Woomera (STADAN), | δ | 0 | +1 | 0 | -.1 | 0 | -.1 | 0 | -.1 |
| Woomera (SAO) | α | 0 | 0 | 0 | 0 | 0 | 0 | +1 | +1 |

^o Maui data RMS of fit to reference arc - 2.7 arcsecs δ , 1.2 arcsecs α

* Declination

** Right ascension

\dagger Latitude movement of station position

\ddagger Longitude movement of station position

Effect of Errors Introduced Into the Station Positions of Various Stations or Station Groupings
on the RMS of Fit of Organ Pass Data^o

| Station or Station Groups Into Which Errors Were Introduced to Determine New Orbits | Measurement Type | Change in RMS of fit (seconds of arc) due to station position shifts of | | | | | | | |
|---|------------------|---|-----------------|-----------------------------|--------------------|-----------------|-----------------|--------------------|--------------------|
| | | +30 m ϕ^\dagger | -30 m ϕ | +30 m λ^\ddagger | -30 m λ | +60 m ϕ | -60 m ϕ | +60 m λ | -60 m λ |
| Maui | δ^* | 0 | -.1 | -.1 | -.1 | | | | |
| | α^{**} | +1 | -.1 | -.1 | 0 | | | | |
| Organ Pass | δ | +2 | +8 | +1 | +3 | | | | |
| | α | +1 | +2 | +8 | -.1 | | | | |
| Jupiter | δ | +2 | -.1 | 0 | 0 | | | | |
| | α | +1 | -.1 | -.2 | +3 | | | | |
| Naini Tal, Shiraz | δ | 0 | -.1 | 0 | -.1 | | | | |
| | α | 0 | 0 | -.1 | +1 | | | | |
| Arequipa, Villa Dolores | δ | -.1 | 0 | -.1 | -.1 | | | | |
| | α | 0 | 0 | -.1 | 0 | | | | |
| Johannesburg, Olifantsfontein, Tananarive | δ | -.2 | +1 | 0 | 0 | -.2 | +3 | 0 | 0 |
| | α | +1 | -.1 | 0 | 0 | +2 | -.1 | 0 | 0 |
| Woomera (STADAN), Woomera (SAO) | δ | -.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | α | 0 | -.1 | 0 | 0 | +1 | -.1 | 0 | 0 |

^o Organ Pass data RMS of fit to reference arc - 1.7 arcsecs δ , 1.8 arcsecs α

* Declination

** Right ascension

[†] Latitude movement of station position

[‡] Longitude movement of station position

Effect of Errors Introduced Into the Station Positions of Various Stations or Station Groupings
on the RMS of Fit of Jupiter Data^o

| Station or Station Groups Into Which Errors Were Introduced to Determine New Orbits | Measurement Type | Change in RMS of fit (seconds of arc) due to station position shifts of | | | | | | | |
|---|------------------------|---|--------------|------------------------------|-----------------|--------------|--------------|-----------------|-----------------|
| | | +30 m ϕ [†] | -30 m ϕ | +30 m λ [‡] | -30 m λ | +60 m ϕ | -60 m ϕ | +60 m λ | -60 m λ |
| Maui | δ [*] | 0 | -.1 | 0 | -.1 | | | | |
| | α ^{**} | 0 | 0 | 0 | 0 | | | | |
| Organ Pass | δ | 0 | 0 | +1 | -.1 | | | | |
| | α | -.1 | +1 | -.1 | +1 | | | | |
| Jupiter | δ | +6 | +5 | -.1 | +5 | | | | |
| | α | +4 | -.3 | +6 | +2 | | | | |
| Naini Tal, Shiraz | δ | 0 | 0 | 0 | -.1 | | | | |
| | α | -.1 | 0 | -.1 | 0 | | | | |
| Arequipa, Villa Dolores | δ | 0 | 0 | -.1 | 0 | | | | |
| | α | -.1 | 0 | 0 | 0 | | | | |
| Johannesburg, Olifantsfontein, Tananarive | δ | 0 | 0 | 0 | 0 | +3 | +2 | 0 | 0 |
| | α | -.1 | +1 | 0 | 0 | -.2 | +2 | 0 | +1 |
| Woomera (STADAN), Woomera (SAO) | δ | 0 | -.1 | -.1 | 0 | 0 | 0 | -.1 | +1 |
| | α | -.1 | 0 | -.1 | 0 | -.1 | 0 | -.1 | 0 |

^o Jupiter data RMS of fit to reference arc - 1.7 arcsecs δ , 1.8 arcsecs α

^{*} Declination

^{**} Right ascension

[†] Latitude movement of station position

[‡] Longitude movement of station position

Effect of Errors Introduced Into the Station Positions of Various Stations or Station Groupings
on the RMS of Fit of Sudbury Data⁶

| Station or Station Groups Into Which Errors Were Introduced to Determine New Orbits | Measurement Type | Change in RMS of fit (seconds of arc) due to station position shifts of | | | | | | | |
|---|------------------|---|-----------------|-----------------------------|--------------------|-----------------|-----------------|--------------------|--------------------|
| | | +30 m ϕ^\dagger | -30 m ϕ | +30 m λ^\ddagger | -30 m λ | +60 m ϕ | -60 m ϕ | +60 m λ | -60 m λ |
| Maui | δ^* | +1 | -.2 | -.1 | -.1 | | | | |
| | α^{**} | 0 | -.2 | -.1 | -.2 | | | | |
| Organ | δ | +1 | -.3 | -.2 | 0 | | | | |
| Pass | α | +1 | -.3 | +3 | -.4 | | | | |
| Jupiter | δ | +3 | -.4 | -.2 | +1 | | | | |
| | α | +1 | -.3 | +3 | -.4 | | | | |
| Naini Tal, | δ | +1 | -.2 | -.1 | 0 | | | | |
| Shiraz | α | 0 | -.2 | +1 | -.3 | | | | |
| Arequipa, | δ | -.2 | 0 | 0 | -.2 | | | | |
| Villa Dolores | α | -.1 | -.1 | -.2 | -.1 | | | | |
| Johannesburg, | δ | -.3 | +1 | +1 | -.2 | -.5 | +4 | +2 | -.3 |
| Olifantsfontein, | α | -.1 | -.2 | -.1 | 0 | 0 | -.2 | -.1 | 0 |
| Tananarive | | | | | | | | | |
| Woomera (STADAN), | δ | 0 | -.1 | 0 | -.1 | 0 | -.1 | +1 | -.3 |
| Woomera (SAO) | α | -.1 | -.1 | -.1 | 0 | -.1 | -.1 | -.2 | 0 |

⁶ Sudbury data RMS of fit to reference arc - 2.2 arcsecs δ , 1.3 arcsecs α

* Declination

** Right ascension

[†] Latitude movement of station position

[‡] Longitude movement of station position

Effect of Errors Introduced Into the Station Positions of Various Stations or Station Groupings
on the RMS of Fit of Bermuda Data^o

| Station or Station Groups Into Which Errors Were Introduced to Determine New Orbits | Measurement Type | Change in RMS of fit (seconds of arc) due to station position shifts of | | | | | | | |
|---|------------------|---|-----------------|-----------------------------|--------------------|-----------------|-----------------|--------------------|--------------------|
| | | +30 m ϕ^\dagger | -30 m ϕ | +30 m λ^\ddagger | -30 m λ | +60 m ϕ | -60 m ϕ | +60 m λ | -60 m λ |
| Maui | δ^* | +1 | -.3 | -.2 | 0 | | | | |
| | α^{**} | 0 | -.2 | -.1 | -.2 | | | | |
| Organ | δ | +3 | -.5 | -.3 | +1 | | | | |
| Pass | α | +2 | -.4 | +3 | -.5 | | | | |
| Jupiter | δ | +5 | -.6 | -.4 | +3 | | | | |
| | α | +2 | -.4 | +2 | -.3 | | | | |
| Naini Tal, | δ | +2 | -.3 | -.2 | +1 | | | | |
| Shiraz | α | 0 | -.3 | +1 | -.3 | | | | |
| Arequipa, | δ | -.1 | -.1 | 0 | -.1 | | | | |
| Villa Dolores | α | -.1 | -.2 | -.2 | -.1 | | | | |
| Johannesburg, | δ | -.1 | -.1 | +1 | -.1 | -.1 | -.1 | +1 | -.3 |
| Olifantsfontein, | α | 0 | -.3 | -.1 | -.1 | +1 | -.4 | -.1 | -.1 |
| Tananarive | | | | | | | | | |
| Woomera (STADAN) | δ | 0 | -.2 | +1 | -.2 | +1 | -.2 | +2 | -.3 |
| Woomera (SAO) | α | -.1 | -.2 | -.1 | 0 | 0 | -.1 | -.2 | 0 |

^o Bermuda data RMS of fit to reference arc - 2.7 arcsecs δ , 3.1 arcsecs α

*Declination

**Right ascension

† Latitude movement of station position

‡ Longitude movement of station position

Effect of Errors Introduced Into the Station Positions of Various Stations or Station Groupings
on the RMS of Fit of San Fernando Data^o

| Station or Station Groups Into Which Errors Were Introduced to Determine New Orbits | Measurement Type | Change in RMS of fit (seconds of arc) due to station position shifts of | | | | | | | |
|---|------------------|---|-----------------|----------------------|--------------------|-----------------|-----------------|--------------------|--------------------|
| | | +30 m ϕ † | -30 m ϕ | +30 m λ ‡ | -30 m λ | +60 m ϕ | -60 m ϕ | +60 m λ | -60 m λ |
| Maui | δ ‡ | 0 | +2 | +2 | 0 | | | | |
| | α ‡ | 0 | -1 | -1 | 0 | | | | |
| Organ Pass | δ | -3 | +5 | 0 | +2 | | | | |
| | α | 0 | -2 | +1 | 0 | | | | |
| Jupiter | δ | -4 | +6 | +1 | +1 | | | | |
| | α | +1 | -2 | +1 | 0 | | | | |
| Naini Tal, Shiraz | δ | -2 | -4 | 0 | +1 | | | | |
| | α | 0 | -1 | 0 | -1 | | | | |
| Arequipa, Villa Dolores | δ | +1 | +1 | +1 | +1 | | | | |
| | α | -1 | -1 | -1 | -1 | | | | |
| Johannesburg, Olifantsfontein, | δ | +1 | +1 | +1 | +1 | 0 | +2 | 0 | +1 |
| | α | 0 | -2 | 0 | -1 | +2 | -1 | 0 | -1 |
| Tanaparive | δ | 0 | +1 | 0 | +1 | +1 | +1 | -1 | +2 |
| | α | -1 | -1 | -1 | -1 | 0 | -1 | -1 | -1 |
| Woomera (STADAN), Woomera (SAO) | δ | 0 | +1 | 0 | +1 | +1 | +1 | -1 | +2 |
| | α | -1 | -1 | -1 | -1 | 0 | -1 | -1 | -1 |

^oSan Fernando data RMS of fit to reference arc - 2.4 arcsecs δ , 1.7 arcsecs α

‡ Declination

** Right ascension

† Latitude movement of station position

‡ Longitude movement of station position

Effect of Errors Introduced Into the Station Positions of Various Stations or Station Groupings
on the RMS of Fit of Naini Tal Data°

| Station or Station Groups Into Which Errors Were Introduced to Determine New Orbits | Measurement Type | Change in RMS of fit (seconds of arc) due to station position shifts of | | | | | | | |
|---|------------------|---|-----------------|-----------------------------|--------------------|-----------------|-----------------|--------------------|--------------------|
| | | +30 m ϕ^\dagger | -30 m ϕ | +30 m λ^\ddagger | -30 m λ | +60 m ϕ | -60 m ϕ | +60 m λ | -60 m λ |
| Maui | δ^* | 0 | -.2 | -.1 | -.2 | | | | |
| | α^{**} | 0 | +1.1 | +1.1 | 0 | | | | |
| Organ Pass | δ | +1.1 | -.4 | +1.1 | -.4 | | | | |
| | α | 0 | +2.2 | +1.1 | 0 | | | | |
| Jupiter | δ | +2.2 | -.5 | +1.1 | -.3 | | | | |
| | α | 0 | +2.2 | +2.2 | 0 | | | | |
| Naini Tal, Shiraz | δ | -.9 | +1.0 | -.9 | +1.1 | | | | |
| | α | +5 | 0 | 0 | +2 | | | | |
| Arequipa, Villa Dolores | δ | -.2 | -.1 | -.1 | -.2 | | | | |
| | α | 0 | +1.1 | +1.1 | 0 | | | | |
| Johannesburg, Olifantsfontein, Tananarive | δ | -.3 | 0 | 0 | -.1 | -.4 | +2 | 0 | -.2 |
| | α | 0 | +2.2 | +1.1 | +1.1 | -.1 | +3 | +1 | +1 |
| Woomera (STADAN), Woomera (SAO) | δ | -.1 | -.1 | -.1 | -.1 | -.1 | 0 | -.1 | -.2 |
| | α | 0 | +1.1 | +1.1 | +1.1 | 0 | +1 | 0 | +1 |

° Naini Tal data RMS of fit to reference arc - 2.3 arcsecs δ , 1.6 arcsecs α

* Declination

** Right ascension

† Latitude movement of station position

‡ Longitude movement of station position

Effect of Errors Introduced Into the Station Positions of Various Stations or Station Groupings
on the RMS of Fit of Shiraz Data[°]

| Station or Station Groups Into Which Errors Were Introduced to Determine New Orbits | Measurement Type | Change in RMS of fit (seconds of arc) due to station position shifts of | | | | | | | |
|---|------------------|---|-----------------|-----------------------------|--------------------|-----------------|-----------------|--------------------|--------------------|
| | | +30 m ϕ^\dagger | -30 m ϕ | +30 m λ^\ddagger | -30 m λ | +60 m ϕ | -60 m ϕ | +60 m λ | -60 m λ |
| Maui | δ^* | -.1 | +.2 | +.2 | -.1 | | | | |
| | α^{**} | -.1 | 0 | 0 | -.1 | | | | |
| Organ Pass | δ | -.3 | +.5 | +.2 | -.1 | | | | |
| | α | 0 | -.1 | +.3 | -.2 | | | | |
| Jupiter | δ | -.4 | +.8 | +.3 | -.2 | | | | |
| | α | 0 | -.1 | +.4 | -.2 | | | | |
| Naini Tal, Shiraz | δ | +2.8 | +.8 | -.6 | +1.0 | | | | |
| | α | -.1 | +.3 | +.4 | +1.7 | | | | |
| Arequipa, Villa Dolores | δ | +.1 | -.1 | 0 | +.1 | | | | |
| | α | 0 | 0 | 0 | -.1 | | | | |
| Johannesburg, Olifantsfontein, Tananarive | δ | +.2 | -.1 | +.1 | 0 | +.5 | -.2 | +.1 | 0 |
| | α | 0 | 0 | 0 | -.1 | 0 | -.1 | +.1 | -.2 |
| Woomera (STADAN), Woomera (SAO) | δ | +.1 | 0 | -.1 | +.2 | +.1 | 0 | -.2 | +.3 |
| | α | -.1 | 0 | 0 | -.1 | -.1 | 0 | 0 | -.1 |

[°] Shiraz data RMS of fit to reference arc - 1.4 arcsecs δ , 2.4 arcsecs α

* Declination

** Right ascension

[†] Latitude movement of station position

[‡] Longitude movement of station position

Effect of Errors Introduced Into the Station Positions of Various Stations or Station Groupings
on the RMS of Fit of Arequipa Data^o

| Station or Station Groups Into Which Errors Were Introduced to Determine New Orbits | Measurement Type | Change in RMS of fit (seconds of arc) due to station position shifts of | | | | | | | |
|---|------------------|---|-----------------|-----------------------------|--------------------|-----------------|-----------------|--------------------|--------------------|
| | | +30 m ϕ^\dagger | -30 m ϕ | +30 m λ^\ddagger | -30 m λ | +60 m ϕ | -60 m ϕ | +60 m λ | -60 m λ |
| Maui | δ^* | +1 | +2 | +1 | +1 | | | | |
| | α^{**} | +1 | +1 | 0 | +2 | | | | |
| Organ Pass | δ | 0 | +1 | +1 | +2 | | | | |
| | α | +1 | +1 | 0 | +2 | | | | |
| Jupiter | δ | 0 | +2 | 0 | 0 | | | | |
| | α | 0 | +1 | -2 | +3 | | | | |
| Naini Tal, Shiraz | δ | 0 | +1 | +1 | +1 | | | | |
| | α | 0 | +1 | 0 | +1 | | | | |
| Arequipa | δ | +2 | +1.6 | +8 | -5 | | | | |
| | α | +2 | 0 | +2.2 | -1.0 | | | | |
| Villa Dolores Johannesburg, Olifantsfontein, Tananarive | δ | +1.1 | -2 | -3 | +4 | +2.3 | +5 | -6 | +9 |
| | α | -1 | +3 | -9 | +1.3 | -2 | +6 | -7 | +2.6 |
| Woomera (STADAN), Woomera (SAO) | δ | +3 | -1 | -1 | +1 | +6 | -2 | -2 | +3 |
| | α | -1 | +3 | -4 | +5 | -3 | +5 | -7 | +1.0 |

^o Arequipa data RMS of fit to reference arc - 2.7 arcsecs δ , 1.2 arcsecs α

* Declination

** Right ascension

\dagger Latitude movement of station position

\ddagger Longitude movement of station position

Effect of Errors Introduced Into the Station Positions of Various Stations or Station Groupings
on the RMS of Fit of Villa Dolores Data°

| Station or Station Groups Into Which Errors Were Introduced to Determine New Orbits | Measurement Type | Change in RMS of fit (seconds of arc) due to station position shifts of | | | | | | | |
|---|------------------|---|-----------------|-----------------------------|--------------------|-----------------|-----------------|--------------------|--------------------|
| | | +30 m ϕ^\dagger | -30 m ϕ | +30 m λ^\ddagger | -30 m λ | +60 m ϕ | -60 m ϕ | +60 m λ | -60 m λ |
| Maui | δ^* | 0 | -.2 | -.1 | -.1 | | | | |
| | α^{**} | +.2 | +.1 | +.1 | +.2 | | | | |
| Organ Pass | δ | -.1 | -.1 | 0 | -.3 | | | | |
| | α | +.1 | +.2 | +.1 | +.2 | | | | |
| Jupiter | δ | +.1 | -.3 | 0 | 0 | | | | |
| | α | +.1 | +.2 | +.1 | 0 | | | | |
| Naini Tal, Shiraz | δ | -.1 | 0 | 0 | -.1 | | | | |
| | α | +.1 | +.1 | +.1 | +.1 | | | | |
| Arequipa, Villa Dolores | δ | +2.9 | -1.2 | +.4 | -.5 | | | | |
| | α | -.5 | +.7 | +3.1 | -2.2 | | | | |
| Johannesburg, Olifantsfontein, Tananarive | δ | -1.7 | +1.8 | -.4 | +.4 | -.5 | +3.8 | -.8 | +.8 |
| | α | +.7 | -.3 | -1.8 | +2.2 | +1.1 | -.8 | -1.7 | +4.4 |
| Woomera (STADAN), Woomera (SAO) | δ | -.7 | +.5 | -.2 | +.2 | -1.2 | +1.4 | -.5 | +.4 |
| | α | +.2 | +.1 | -.6 | +.7 | +.2 | -.1 | -1.2 | +1.4 |

° Villa Dolores data RMS of fit to reference arc - 2.4 arcsecs δ , 3.4 arcsecs α

* Declination

** Right ascension

† Latitude movement of station position

‡ Longitude movement of station position

Effect of Errors Introduced Into the Station Positions of Various Stations or Station Groupings
on the RMS of Fit of Johannesburg Data°

| Station or Station Groups Into Which Errors Were Introduced to Determine New Orbits | Measurement Type | Change in RMS of fit (seconds of arc) due to station position shifts of | | | | | | | |
|---|------------------|---|-----------------|-----------------------------|--------------------|-----------------|-----------------|--------------------|--------------------|
| | | +30 m ϕ^\dagger | -30 m ϕ | +30 m λ^\ddagger | -30 m λ | +60 m ϕ | -60 m ϕ | +60 m λ | -60 m λ |
| Maui | δ^* | 0 | +2 | 0 | +1 | | | | |
| | α^{**} | -2 | 0 | -1 | -1 | | | | |
| Organ Pass | δ | 0 | 0 | 0 | +1 | | | | |
| | α | -1 | -1 | -1 | -1 | | | | |
| Jupiter | δ | 0 | +1 | 0 | 0 | | | | |
| | α | -1 | -1 | -1 | -1 | | | | |
| Naini Tal, Shiraz | δ | 0 | 0 | 0 | 0 | | | | |
| | α | -1 | -1 | -1 | -1 | | | | |
| Arequipa, Villa Dolores | δ | +2 | +1 | +1 | +1 | | | | |
| | α | -2 | 0 | +2 | -3 | | | | |
| Johannesburg, Olifantsfontein, Tananarive | δ | +4 | +6 | +3 | 0 | +1.5 | +1.6 | +6 | +2 |
| | α | 0 | -2 | -7 | +8 | +2 | -1 | -9 | +1.8 |
| Woomera (STADAN), Woomera (SAO) | δ | +1 | +1 | 0 | 0 | +2 | +3 | +1 | +1 |
| | α | -1 | -1 | +2 | -3 | -1 | 0 | +5 | -5 |

° Johannesburg data RMS of fit to reference arc - 2.2 arcsecs δ , 3.0 arcsecs α

* Declination

** Right ascension

† Latitude movement of station position

‡ Longitude movement of station position

Effect of Errors Introduced Into the Station Positions of Various Stations or Station Groupings
on the RMS of Fit of Olifantsfontein Data°

| Station or Station Groups Into Which Errors Were Introduced to Determine New Orbits | Measurement Type | Change in RMS of fit (seconds of arc) due to station position shifts of | | | | | | | |
|---|------------------|---|-----------------|----------------------|--------------------|-----------------|-----------------|--------------------|--------------------|
| | | +30 m ϕ † | -30 m ϕ | +30 m λ ‡ | -30 m λ | +60 m ϕ | -60 m ϕ | +60 m λ | -60 m λ |
| Maui | δ^* | 0 | 0 | 0 | 0 | | | | |
| | α^{**} | -.1 | 0 | 0 | -.1 | | | | |
| Organ Pass | δ | 0 | -.1 | 0 | 0 | | | | |
| | α | 0 | -.1 | 0 | -.1 | | | | |
| Jupiter | δ | +1 | -.1 | 0 | 0 | | | | |
| | α | 0 | -.1 | 0 | 0 | | | | |
| Naini Tal, Shiraz | δ | 0 | -.1 | 0 | 0 | | | | |
| | α | 0 | 0 | 0 | -.1 | | | | |
| Arequipa, Villa Dolores | δ | -.1 | +3 | +1 | 0 | | | | |
| | α | -.1 | +1 | +5 | -.4 | | | | |
| Johannesburg, Olifantsfontein, Tananarive | δ | +9 | +1 | 0 | +2 | +2.4 | +1.2 | +3 | +7 |
| | α | +1 | -.2 | -.5 | +1.4 | +5 | -.3 | +1 | +2.5 |
| Woomera (STADAN), Woomera (SAO) | δ | -.1 | +2 | 0 | 0 | 0 | +5 | +1 | -.1 |
| | α | 0 | 0 | +4 | -.3 | +1 | +1 | +8 | -.5 |

° Olifantsfontein data RMS of fit to reference arc - 2.0 arcsecs δ , 2.2 arcsecs α

* Declination

** Right ascension

† Latitude movement of station position

‡ Longitude movement of station position

Effect of Errors Introduced Into the Station Positions of Various Stations or Station Groupings
on the RMS of Fit of Tananarive Data*

| Station or Station Groups Into Which Errors Were Introduced to Determine New Orbits | Measurement Type | Change in RMS of fit (seconds of arc) due to station position shifts of | | | | | | | |
|---|------------------|---|-----------------|-----------------------------|--------------------|-----------------|-----------------|--------------------|--------------------|
| | | +30 m ϕ^\dagger | -30 m ϕ | +30 m λ^\ddagger | -30 m λ | +60 m ϕ | -60 m ϕ | +60 m λ | -60 m λ |
| Maui | δ^* | 0 | 0 | 0 | 0 | | | | |
| | α^{**} | +1 | +2 | +1 | +2 | | | | |
| Organ Pass | δ | +1 | -1 | 0 | 0 | | | | |
| | α | +1 | +1 | +1 | +2 | | | | |
| Jupiter | δ | +2 | -1 | +1 | 0 | | | | |
| | α | +1 | +1 | +1 | 0 | | | | |
| Naini Tal, Shiraz | δ | +1 | 0 | 0 | 0 | | | | |
| | α | +1 | +1 | +1 | +1 | | | | |
| Arequipa, Villa Dolores | δ | -3 | +5 | 0 | +1 | | | | |
| | α | +3 | -1 | -3 | +7 | | | | |
| Johannesburg, Olifantsfontein, Tananarive | δ | +1.1 | -1 | +3 | +2 | +2.4 | +9 | +8 | +7 |
| | α | +1 | +3 | +1.0 | -5 | +1 | +4 | +2.0 | -3 |
| Woomera (STADAN), Woomera (SAO) | δ | -2 | +4 | 0 | +1 | -2 | +9 | 0 | +2 |
| | α | +1 | +1 | -3 | +4 | +1 | 0 | -5 | +9 |

*Tananarive data RMS of fit to reference arc - 1.1 arcsecs δ , 1.7 arcsecs α

*Declination

**Right ascension

\dagger Latitude movement of station position

\ddagger Longitude movement of station position

**Effect of Errors Introduced Into the Station Positions of Various Stations or Station Groupings
on the RMS of Fit of Woomera (SAO) Data^o**

| Station or Station Groups Into Which Errors Were Introduced to Determine New Orbits | Mea- sure- ment Type | Change in RMS of fit (seconds of arc) due to station position shifts of | | | | | | | |
|--|-------------------------------|---|-----------------|-------------------------------|--------------------|-----------------|-----------------|--------------------|--------------------|
| | | +30 m ϕ^{\dagger} | -30 m ϕ | +30 m λ^{\ddagger} | -30 m λ | +60 m ϕ | -60 m ϕ | +60 m λ | -60 m λ |
| Maui | δ^{*} | +1 | +1 | +1 | +1 | | | | |
| | α^{**} | 0 | -1 | 0 | -1 | | | | |
| Organ | δ | +1 | 0 | 0 | +2 | | | | |
| Pass | α | +1 | -1 | -1 | -1 | | | | |
| Jupiter | δ | 0 | +1 | 0 | +1 | | | | |
| | α | 0 | -1 | 0 | -1 | | | | |
| Naini Tal, | δ | 0 | 0 | 0 | +1 | | | | |
| Shiraz | α | +1 | 0 | 0 | -1 | | | | |
| Arequipa, | δ | +1 | -1 | +1 | -1 | | | | |
| Villa Dolores | α | +1 | -1 | +1 | -1 | | | | |
| Johannesburg, | δ | +1.5 | -1 | +1 | -1 | +1.0 | +1 | +1.0 | -1 |
| Olifantsfontein, | α | +1.2 | -1 | +1 | -1 | +1.7 | +1 | +1.5 | +1.1 |
| Tananarive | | | | | | | | | |
| Woomera (STADAN), | δ | +1.2 | +1.4 | +1 | +1 | +1.0 | +1.7 | 0 | +1.1 |
| Woomera (SAO) | α | +1 | +1 | +1.0 | +1.8 | +1 | +1 | +1.4 | +1.1 |

^o Woomera (SAO) data RMS of fit to the reference arc = 2.0 arcsecs δ , 2.0 arcsecs α

* Declination

** Right ascension

\dagger Latitude movement of station position

\ddagger Longitude movement of station position